52nd meeting of the PAC for Condensed Matter Physics, Radiation and Radiobiological research. 02 July 2020

Theme "Novel Semiconductor Detectors for Fundamental and Applied Research" and proposal for its extension

Georgy Shelkov

Novel Semiconductor Detectors for Fundamental and Applied Research

Theme: 04-2-1126-2015/2020

List of projects:

	Project	Leader	Priority (period of realization)
1.	Novel semiconductor detectors for fundamental and applied research	G.A. Shelkov	1 (2015 – 2020)
2.	Development of experimental techniques and applied research with slow monochromatic positron beams (PAS)	A.G. Kobets P. Horodek Scientific leader: I.N. Meshkov	1 (2016 – 2020)
3.	GDH&SPASCHARM	Yu. Usov A. Kovalik	1 (2011 – 2022)

List of participants from JINR

Laboratory	№№	Name	№№	Name
DLNP	1	Shelkov G	2	Gongadze A.
	3	Gostkin M	4	Zhemchugov A.
	5	Kruchonok V.	6	Kozhevnikov D.
	7	Kuznetsov N.	8	Lapkin A.
	9	Leyva A	10	Porokhovoy S.
	11	Rastorguev D.	12	Rozhkov V.
	13	Rudenko T.	14	Smolyanski P.
	15	Cherepanova E.	16	Shakur S.
	17	Akhmanova E.	18	Kobets A.
	19	Meshkov I.	20	Orlov O.
	21	Rudakov A.	22	Siemek K.
	23	Sidorin A.	24	Soboleva L.
	25	Hilinov V.	26	Yakovenko S.
	27	Bazhanov N.	28	Borisov N.
	29	Dolzhikov A.	30	Fedorov A.
	31	Gapienko I.	32	Gorodnov I.
	33	Gurevich G.	34	Koshevarov V.
	35	Kovalik A.		
VBLHEP	36	Kobets V.		
FLNP	37	Ahmedov A.	38	Kopach Yu.
	39	Telezhnikov C.	40	Kulik M.
FLNR	41	Isatov A.	42	Mitrofanov S.
	43	Teterev Yu.	44	Skuratov V.
BLTP	45	Gerasinmov S.	46	Kamalov S.

Country or International Organization	City	Laboratory
Belarus	Minsk	BSTU
United Kingdom	Glasgow	University
United Kingdom	York	University
United Kingdom	London	University
Vietnam	Ho Chi Minh	NTC
Germany	Bonn	University
Germany	Hamburg	DESY
Germany	Giessen	JLU
Germany	Mainz	JGU
Germany	Bochum	IEPh
Egypt	Cairo	NRRA
Egypt	New Borg	E-JUST
Italy	Pavia	INFN
Izrael	Erusalim	HUJ
Canada	Regina	University
Canada	Sackville	MAU
Canada	Hallfax	SMU
Cuba	Habana	CEADEN
New Zealand	*Christchurch*	University
Poland	Krakow	AGH
Poland	Krakow	NINP PAS
Russia	Arkhangelsk	NArFU
Russia	Dubna	University

Country or International Organization	City	Laboratory
Russia	Moscow	VBAB
Russia	Moscow	MSU
Russia	Troitsk	INR
Russia	Saint Petersburg	SPbSU
Russia	Saint Petersburg	Hospital-122
Russia	Belgorod	University
Russia	Tomsk	TSU
Russia	Tomsk	Politech
Russia	Protvino	IHEP
Russia	Moscow	ITEP
Magurele	Magurele	ISS
USA	Seattle	UW
USA	LA	UOC
USA	Kent	KSU
USA	Amherst	UoMas
Ukraine	Kharkov	IPhT
Ukraine	Kharkov	IE&RT NAS
Croatia	Zagreb	RBI
Switzerland	Geneve	CERN
Switzerland	Basel	University
Czech Republic	Prague	CTU
South Africa	Faur	iThemba LABS
Japan	Tsukuba	KEK

List of activities for 2021-2023.

1. The creation of radiation-resistant semiconductor materials for particle detectors.
2. Creation of a full-scale prototype of a module of a compact radiation-resistant electromagnetic calorimeter together with the FCAL collaboration.
3. Creation of pixel detectors and x-ray tomographs with their use.
4. Develop scientific cooperation with research institutes to explore the possibility of using developed detectors in other fields of science and technology (first of all in the field of healthcare and geology).
5. The study of the formation of defects in materials as a result of various physical influences;
6. Expansion of the existing experimental base of PAS.
7. Commissioning of the linear electron accelerator Linac-200.

Results expected upon completion of the theme.

1. Together with physicists from Tomsk, to search for radiation-resistant modifications of GaAs, including measuring their radiation resistance in neutron and electron beams at JINR;
2. Detectors and electronics based on FPGA and software for Timepix4.
3. The current prototype “head” tomograph
4. Conducting joint research with biophysicists of the Moscow Institute of Physics and Technology and Moscow State University using the MARS microtomograph.
5. An advanced DUAL spectrometer with the ability to register the coincidence of two annihilation gamma quanta.
6. Completion of the positron ordering system and commissioning of the PALS spectrometer on a monochromatic positron beam

The main results obtained during the previous stage of the theme

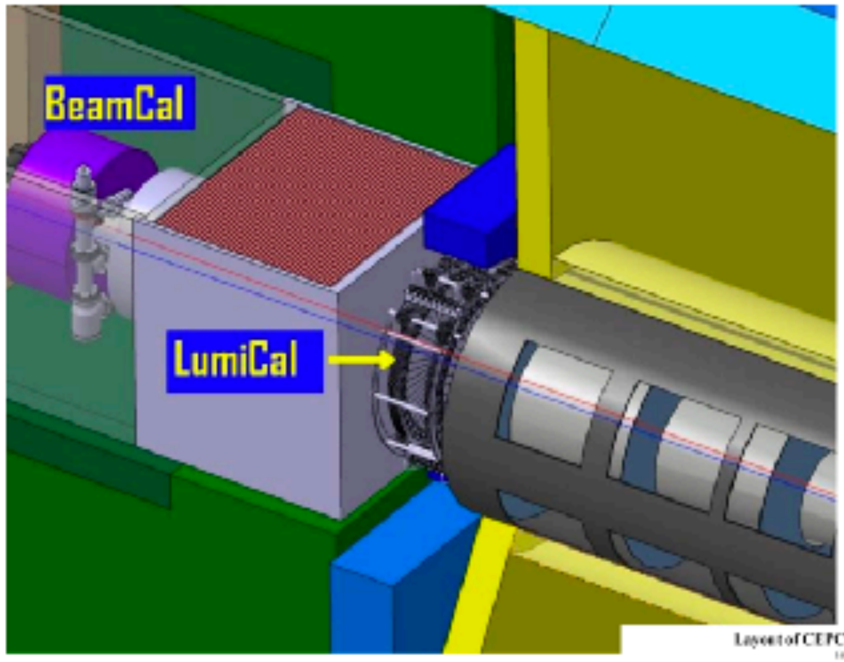
R&D for special calorimeters in the very forward region of future detectors at an e+e- colliders

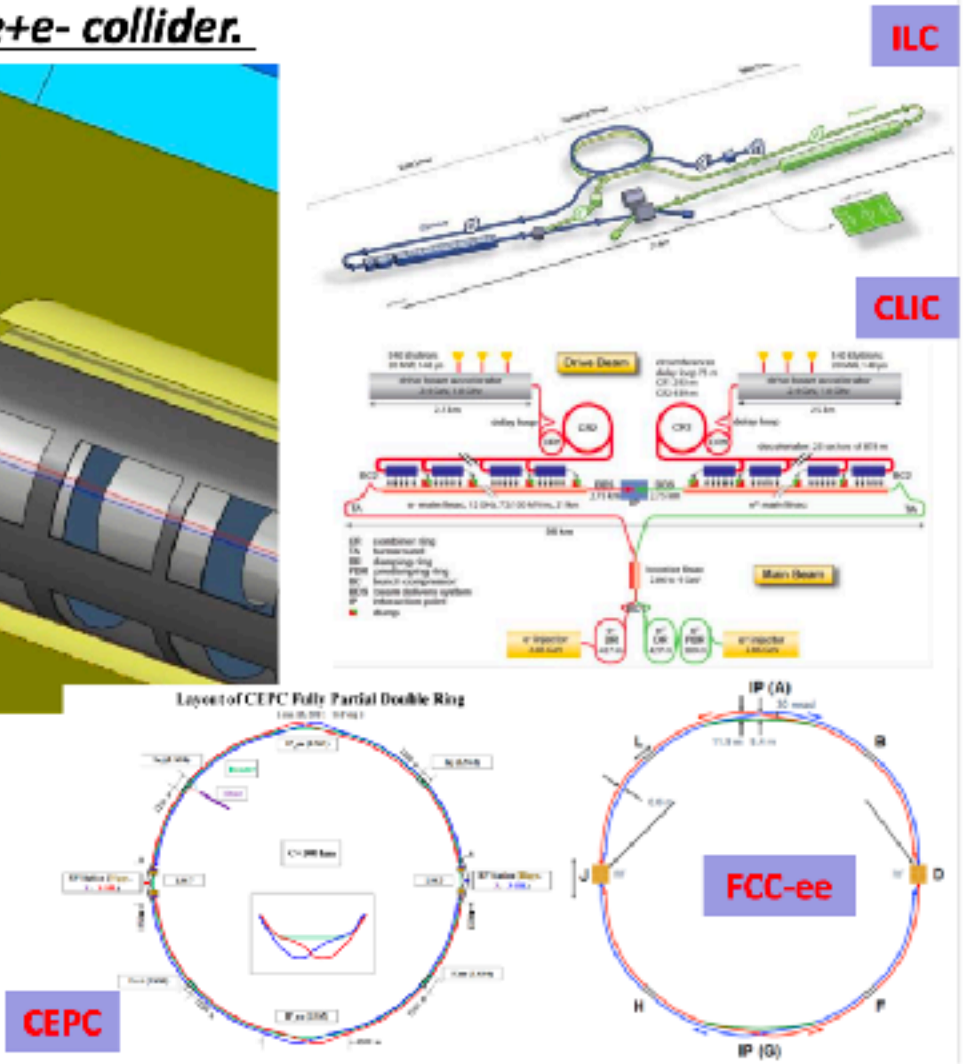
54 members from 14 institutes :

AGH University of science & technology, Krakow, Poland
CERN, Geneva, Switzerland
DESY, Germany
IFJ PAN, PL-31342, Krakow, Poland
ISS, Bucharest, Romania
JINR, Dubna, Russia
National Research Tomsk State University NI TSU, TSU / Russia
NC PHEP, Belarusian State University, Minsk, Belarus
Pontificia Universidad Catolica de Chile, Santiago, Chile
Taras Shevchenko National University of Kiyv, Ukraine
Tel Aviv University, Tel Aviv, Israel
Tohoku University, Sendai, Japan
University of California, Santa Cruz, USA
Vinca Institute of Nuclear Sciences, University of Belgrade, Serbia

We are grateful to the support of the BMBF-JINR program for detector R&D.
FCAL is supported by national funding agencies and programs of the European Community.

R&D for special calorimeters in the very forward region of future detectors at an e+e- collider.





- compact,
- precise shower position measurement
- read out very fast
- radiation hardness

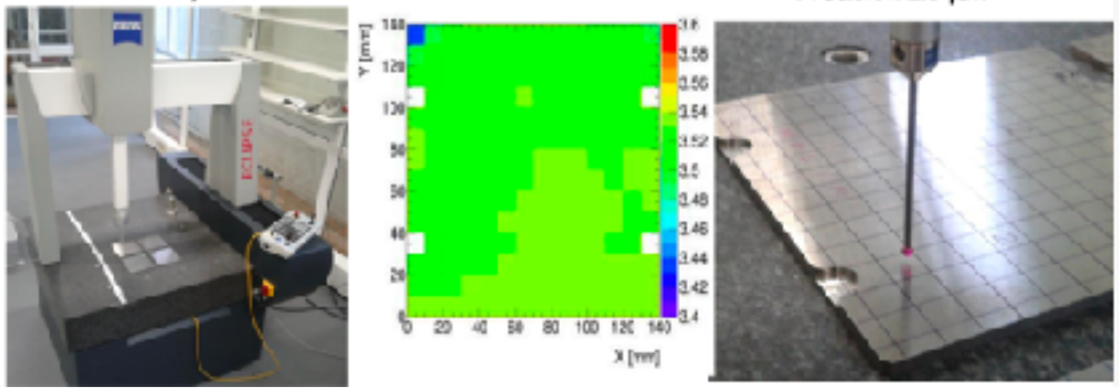
LumiCal and BeamCal – electromagnetic sampling calorimeters

- The technology of a Semiconductor-Tungsten sandwich calorimeter is under investigation:

  Sensors for the LumiCal - Si; for the BeamCal GaAs or sapphire.
- layers of 140x140x3.5 mm (1 X_0) thick tungsten plates with 1 mm gap for silicon sensors (30 for ILC, 40 for CLIC)
- Good flatness ~30 μm were achieved

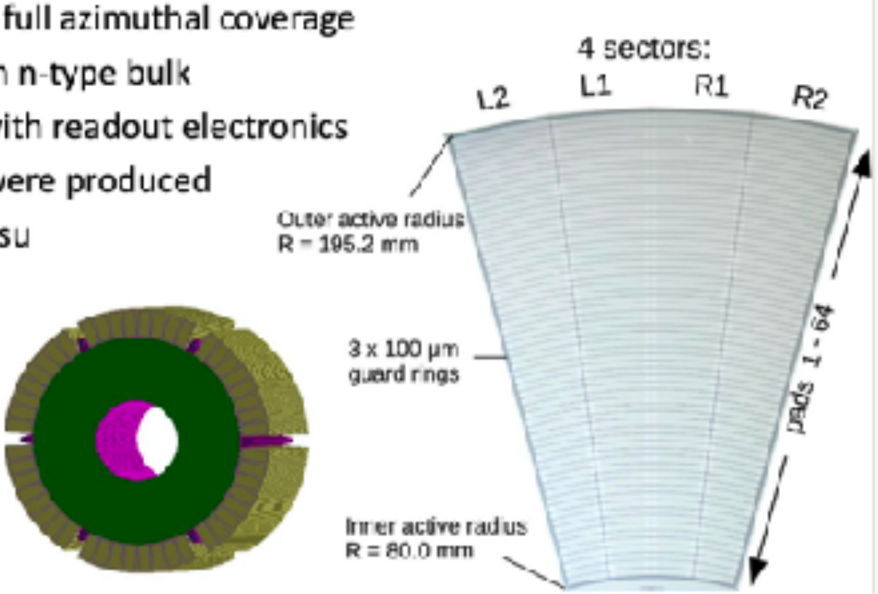
Zeiss 3D coordinate measurement system

Precision 2.5 μm



LumiCal sensor

- Silicon sensor, 320 μm thickness
- 64 radial pads, pitch 1.8 mm
- 4 azimuthal sectors in one tile, each 7.5 degrees
- 12 tiles make full azimuthal coverage
- p+ implants in n-type bulk
- DC coupled with readout electronics
- 40 modules were produced by Hamamatsu



LumiCal and BeamCal in future e+e- accelerators

LumiCal provide:

- precise determination of the integrated luminosity by measuring the rate of Bhabha events at low angles.

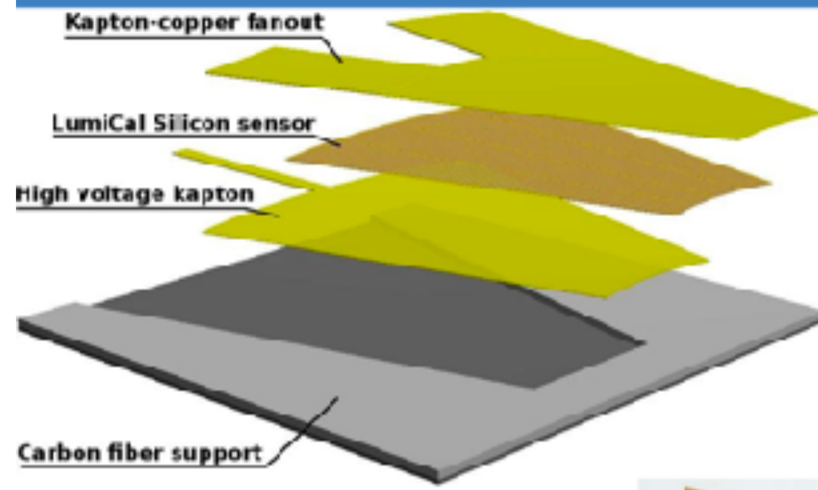
BeamCal:

- device for fast, bunch-by-bunch crossing luminosity using beamstrahlung. Radiation hardness is an issue.

LumiCal and BeamCal:

- improving the hermeticity of the detector by providing electron and photon identification down to polar angles of a few mrad.
- to extend calorimetric coverage to small polar angles. Important for physics analysis.

Detector plane assembly

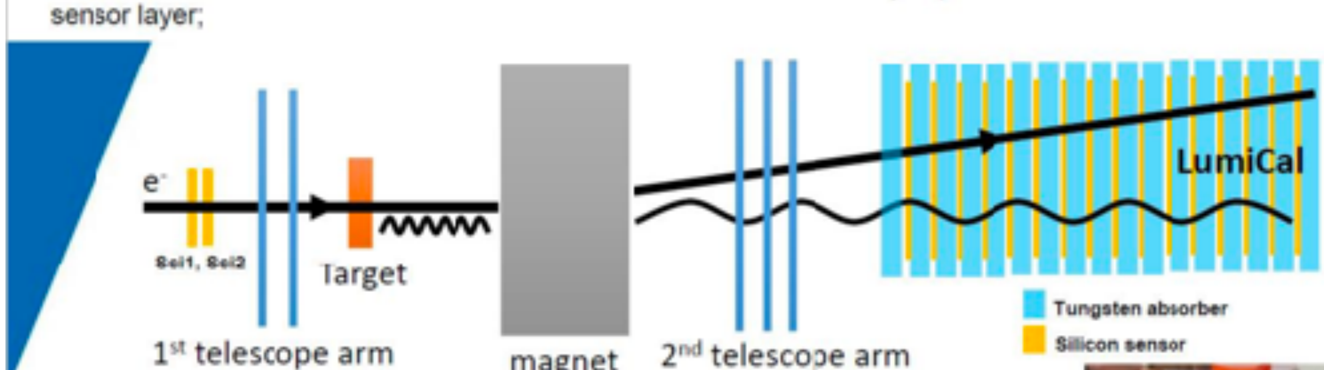


total thickness 650 µm

LumiCal test at DESY in 2019

Experimental set-up

- Test beam at DESY with 1 – 6 GeV electron beam
- ALPIDE telescope – 2 arms, 1st arm consists of 2 layers and 2nd arm consists of 3 layers;
- Target of tungsten with 90µm thickness;
- **Lumical** calorimeter consists of 16 Si sensors with one absorber layer placed in front of each active sensor layer;



Experimental set-up

The ALPIDE chip measures 15x30 mm and includes a matrix of 512x1024 pixel cells

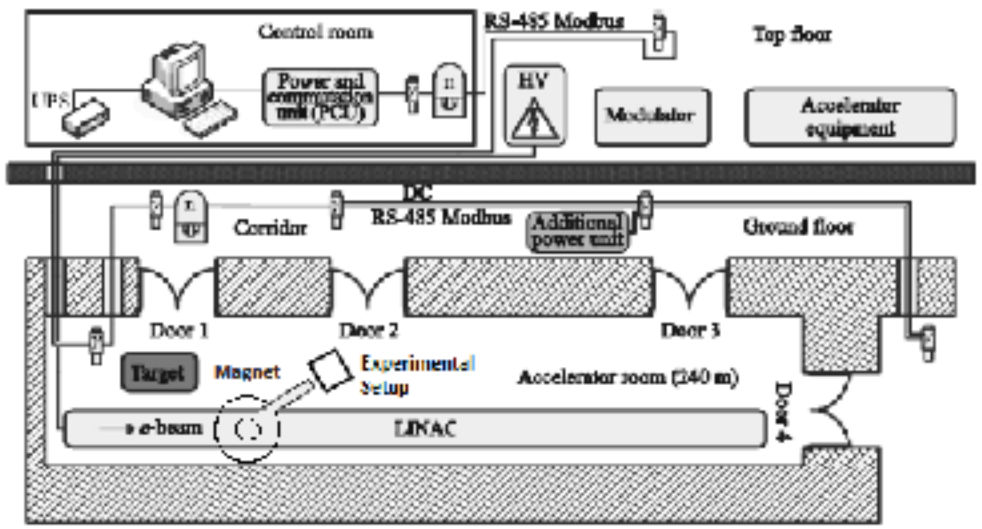
LumiCal plane consist of 256 pads, during the test beam only 128pads were read-out using an APV-25 board

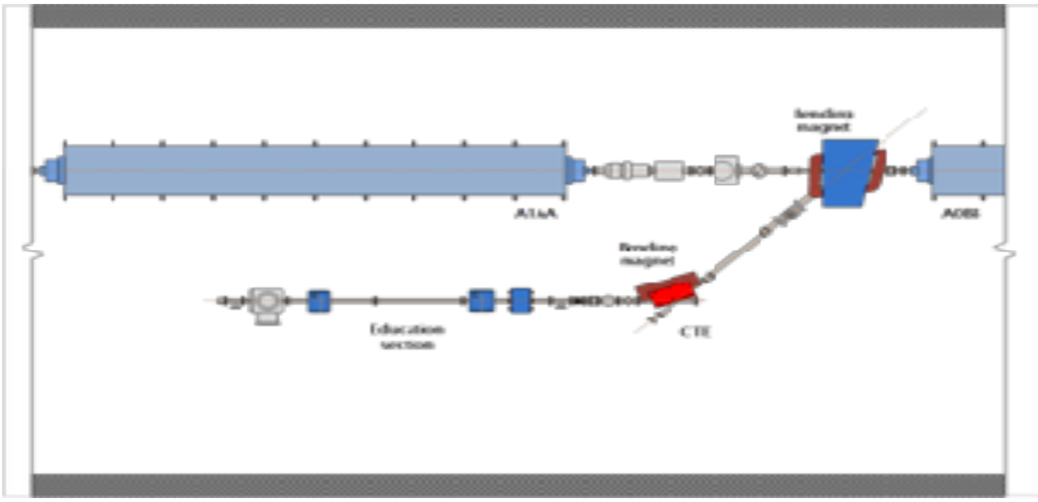
3 million events acquired in LumiCal

Work is ongoing on analysing November 2019 test beam data

The main results obtained during the previous stage of the theme

Radiation hardness of GaAs:Cr and Si was investigated on LINAC-200





Conclusions

1. **After dose of 1.5 MGy :**
   - **in GaAs:Cr sensors signal CCE drops to ~10% of initial, when in Si above 80%**
   - **dark current grows 3-7 times in GaAs:Cr and 4 orders of magnitude in Si.**
   - **In Si full depletion voltage is rising with irradiation, more strong for tick HPK sensors.**
2. **At room temperature, the signal-to-noise ratio in GaAs: Cr sensors is higher than that for Si sensors after a dose of 1.5 MGy, and vice versa when cooled to -20 °C.**

RADIATION HARDNESS OF GaAs:Cr AND Si SENSORS IRRADIATED BY ELECTRON BEAM

U.Kruchonak[a,1], S. Abou El-Azm[a], K. Afanaciev[b], G. Chelkov[a], M. Demichev[a], M. Gostkin[a], A. Guskov[a], E. Firu[c], V. Kobets[a], A. Leyva[a,d], A. Nozdrin[a], S. Porokhovoy[a], A. Sheremetyeva[a], P. Smolyanskiy[a], A. Torres[e], A.Tyazhev[f], O. Tolbanov[f], N. Zamyatin[a], A. Zarubin[f] and A. Zhemchugov[a]

[a] *JINR, Dubna, Russia,* [b] *INP, Minsk, Belarus,* [c] *ISS, Bucharest, Romania ,* [d] *CEADEN, Havana, Cuba*
[e] *InSTEC, Havana, Cuba,* [f] *TSU, Tomsk, Russia*

[1] Corresponding author *E-mail*: Uladzimir.Kruchonak@cern.ch

Accepted to NIMA-D

The main results obtained during the previous stage of the theme

Analysis of the Radiation Field in ATLAS Cavern Using 2017-2018 Data from the ATLAS-GaAsPix Network

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I. Boyko,[a] M. Campbell,[b] E. Cherepanova,[a] G. Chelkov,[a,c,d] D. Dedovich,[a] B. Di Girolamo,[b] A. Gongadze,[a] J. Janecek,[e] D. Kharchenko,[a] U. Kruchonak,[a] M. Nessi,[b] L. Pontecorvo,[b] S. Pospisil,[e] Y. Mora Sierra,[e] P. Smolyanskiy,[a] M. Suk,[e] I. Stekl,[e] O. Tolbanov,[c] A. Tyazhev,[c] A. Zarubin,[c]

[a] *Joint Institute for Nuclear Research, Dubna, Russia*

[b] *CERN, Geneva, Switzerland*

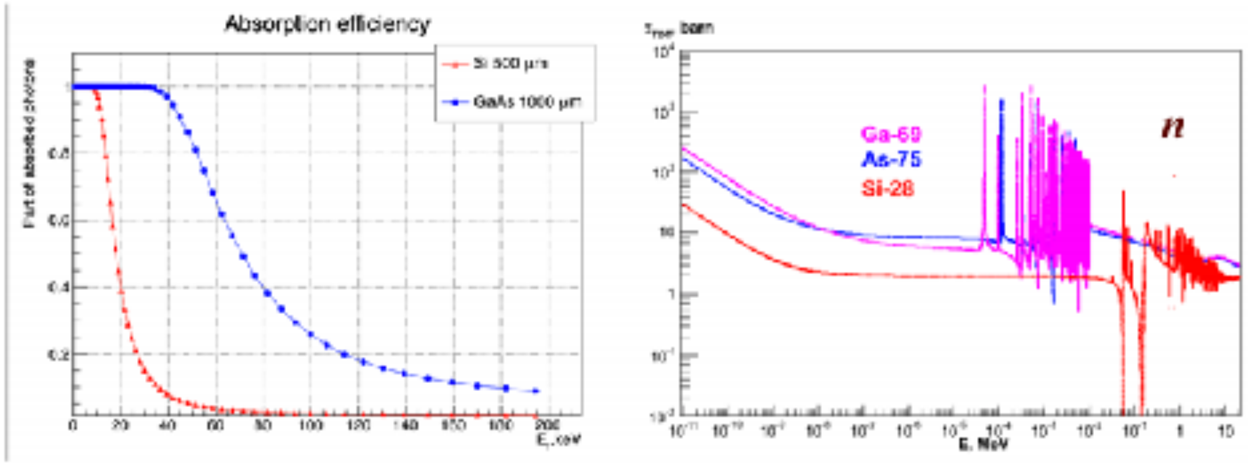
[c] *Tomsk State University, Tomsk, Russia*

[d] *Moscow Institute of Physics and Technology, Dolgoprudny, Russia*

[e] *Institute of Experimental and Applied Physics, Czech Technical University in Prague, Prague, Czech Republic*

E-mail: chelkov@jinr.ru

Draft version was written at JINR and is currently being discussed with co-authors.



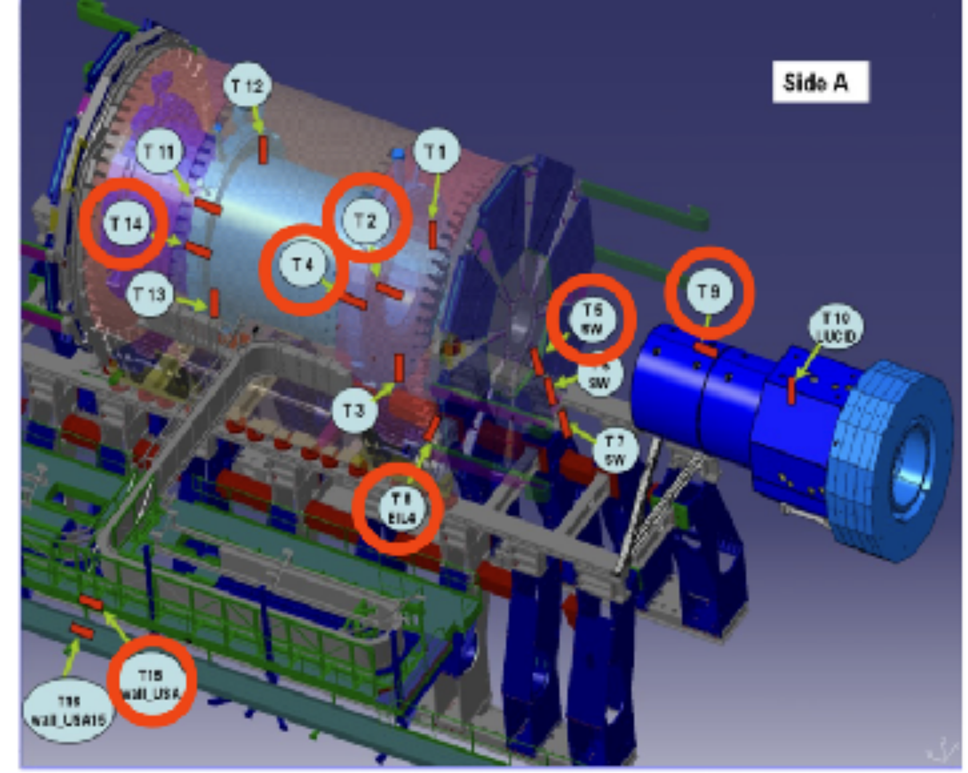
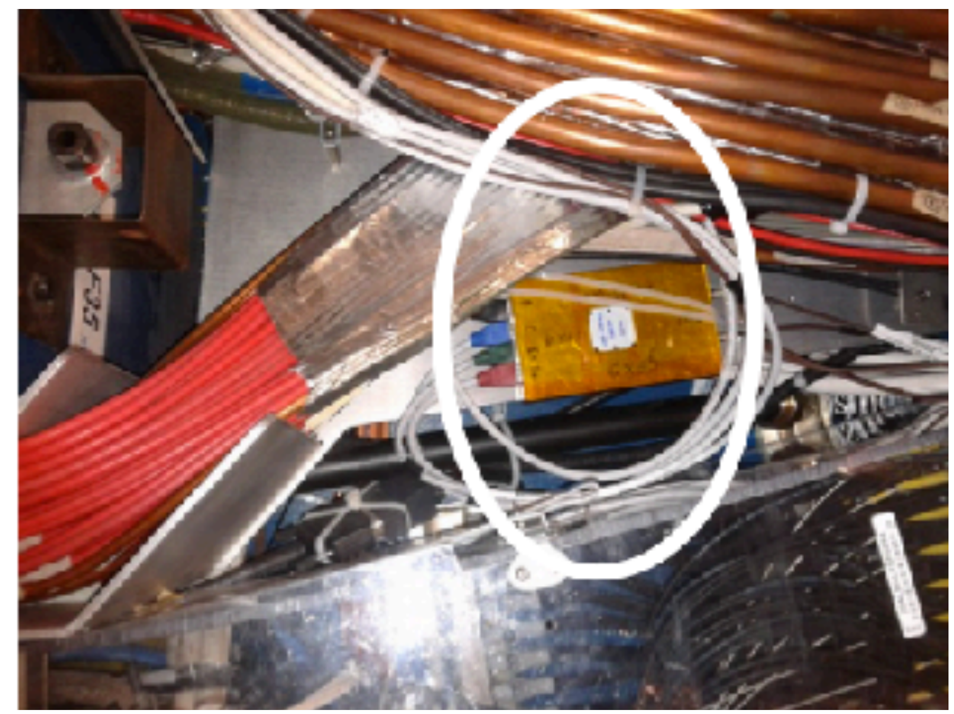
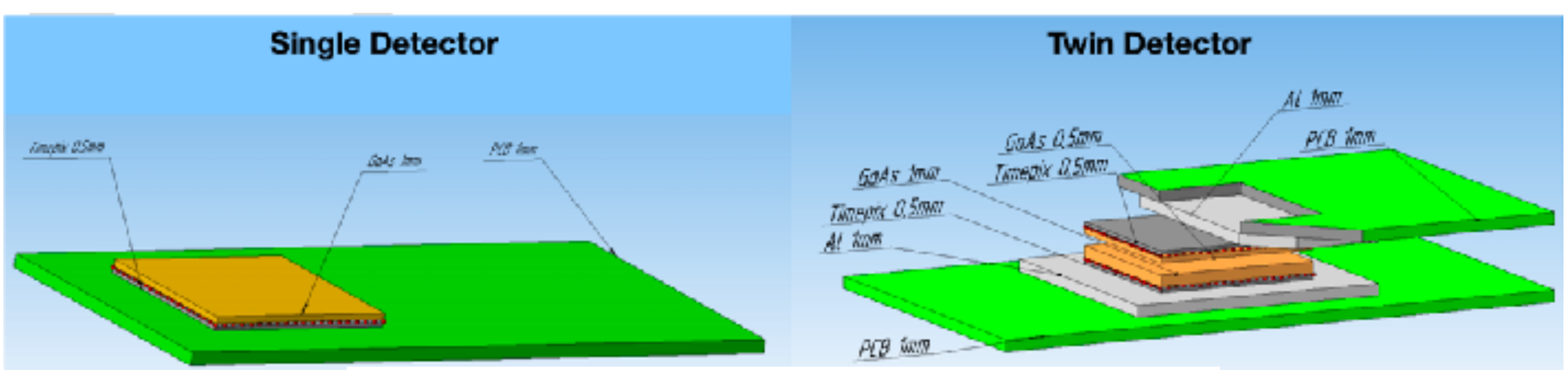


Figure 1. Detection efficiency of 500um Si and 1000um GaAs detectors of γ (left) and neutron (right) cross section of 28Si, 69Ga and 75As dependence on energy γ and neutrons

Table 1. The positions of ATLAS-GaAsPix devices in the ATLAS detector cavern.

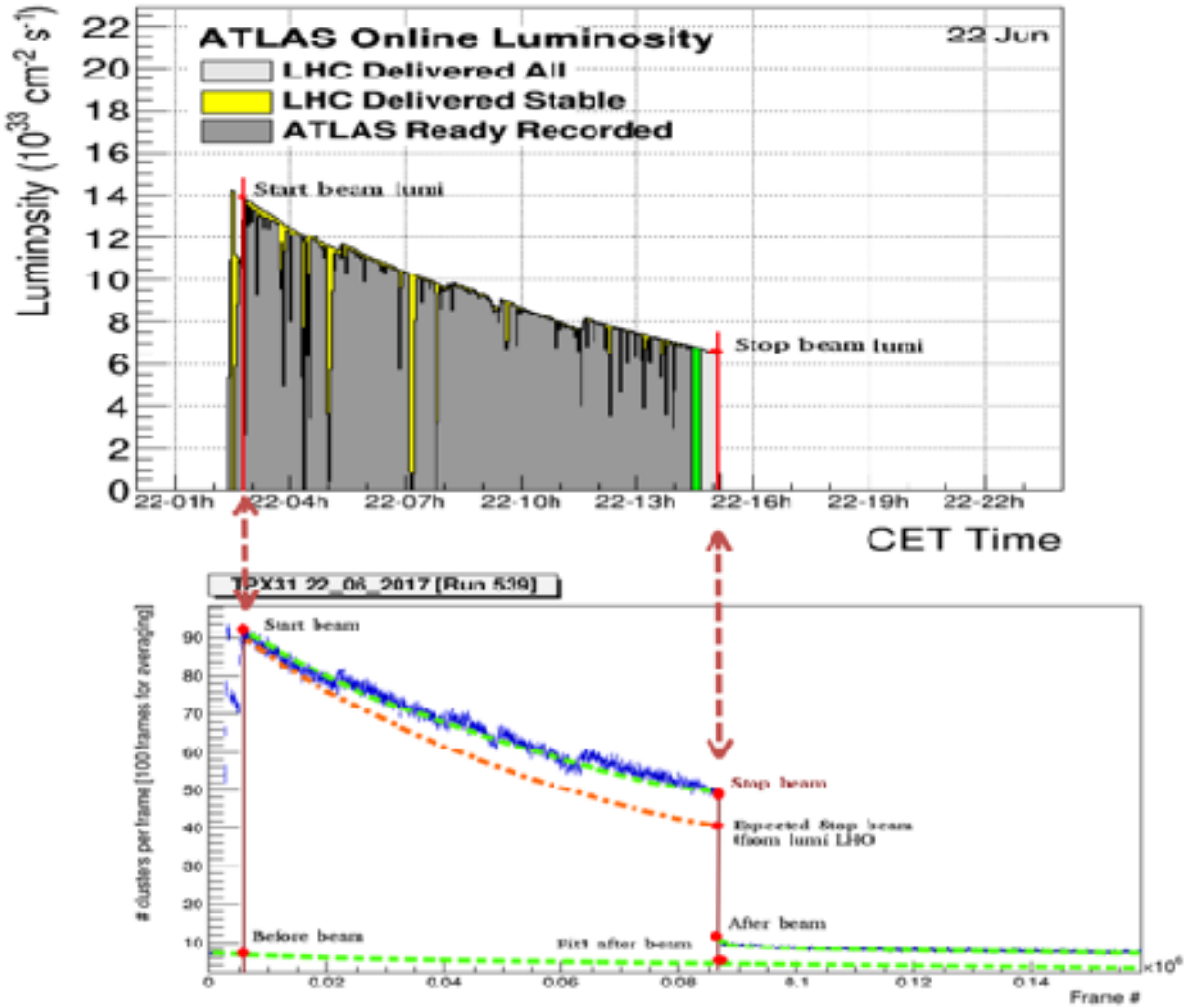
Detector ID	Sensor thickness, μm	X, m	Y, m	Z, m
GPX1	500	-5.98	0	7.22
GPX2	1000	-5.80	0	7.22
GPX3	1000	-16.69	-0.06	5.07
GPX4	500	0	-0.28	-6.74
GPX5	500	0	1.57	-12.86
GPX6	1000/500	-1.12	-0.21	3.53
GPX7	1000/500	0.65	-1.45	7.8
GPX8	1000/1000	0	1.57	15.09
GPX9	1000/500	-3.46	-0.92	2.84
GPX10	1000/500	-3.46	-0.92	-2.84

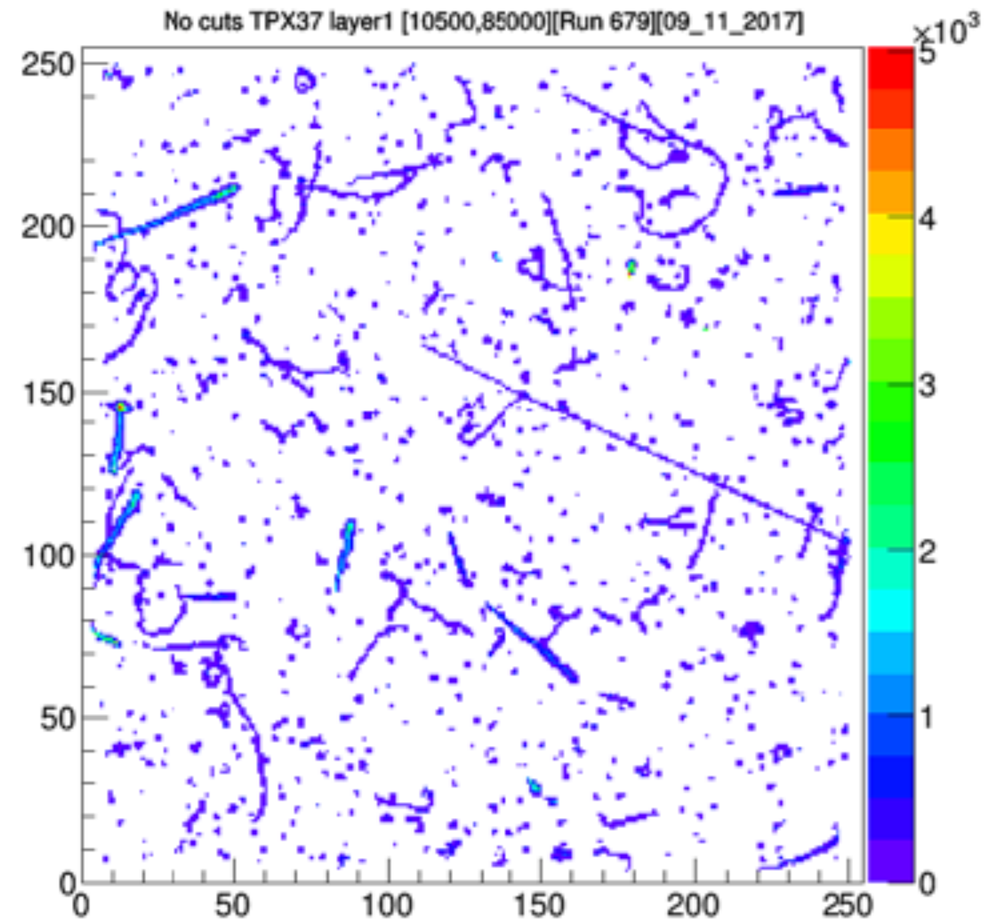




The sketch of single and twin detector assemblies

Структура получаемых данных от детекторов.





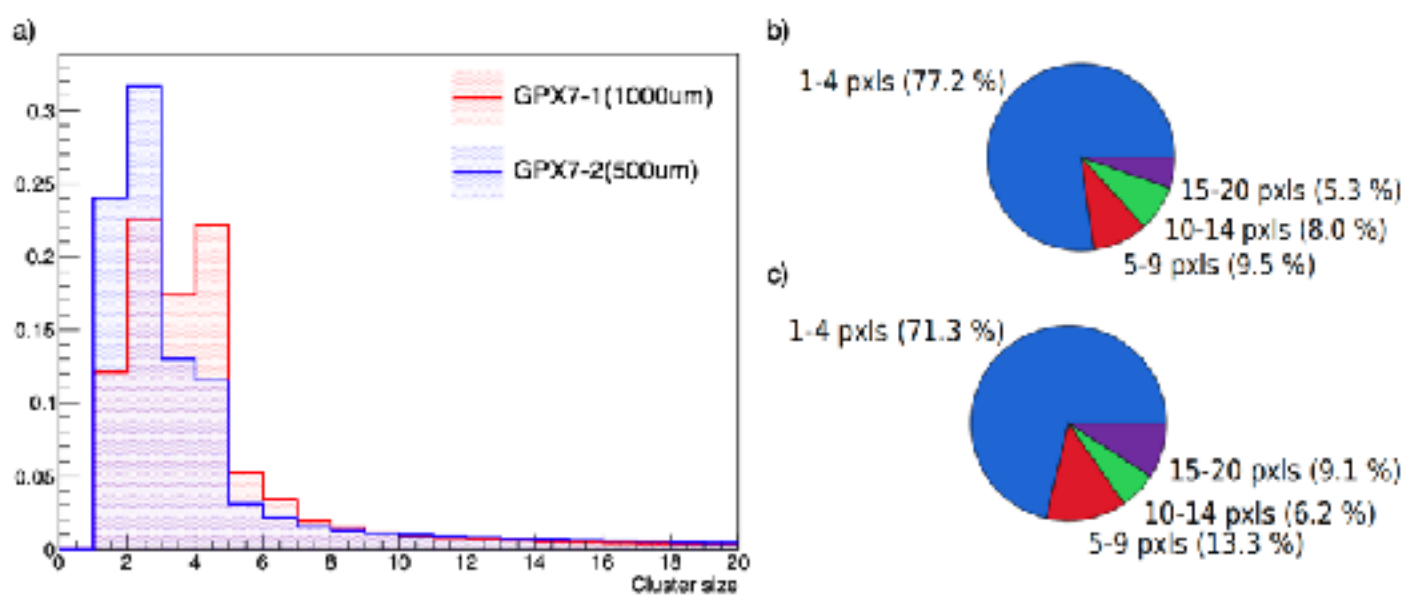


Figure 6. Cluster size distribution for background events of GPX7 that have been detected 20.08.2018: a - distribution for 500μm and 1000μm sensor thicknesses; b - fraction of cluster sizes in 500μm sensor, c - fraction of cluster sizes in 1000μm sensor

Conclusions

1. A network of ten GaAsPix detectors was produced, calibrated, and installed in the ATLAS cavern at the LHC, an environment of intense radiation during beam collisions. Data were accumulated in the years 2017 — 2018 and the operation of the detectors proved stable and reliable.

2. The network of GaAsPix detectors permits measuring and monitoring the radiation environment at different locations around the ATLAS detector.

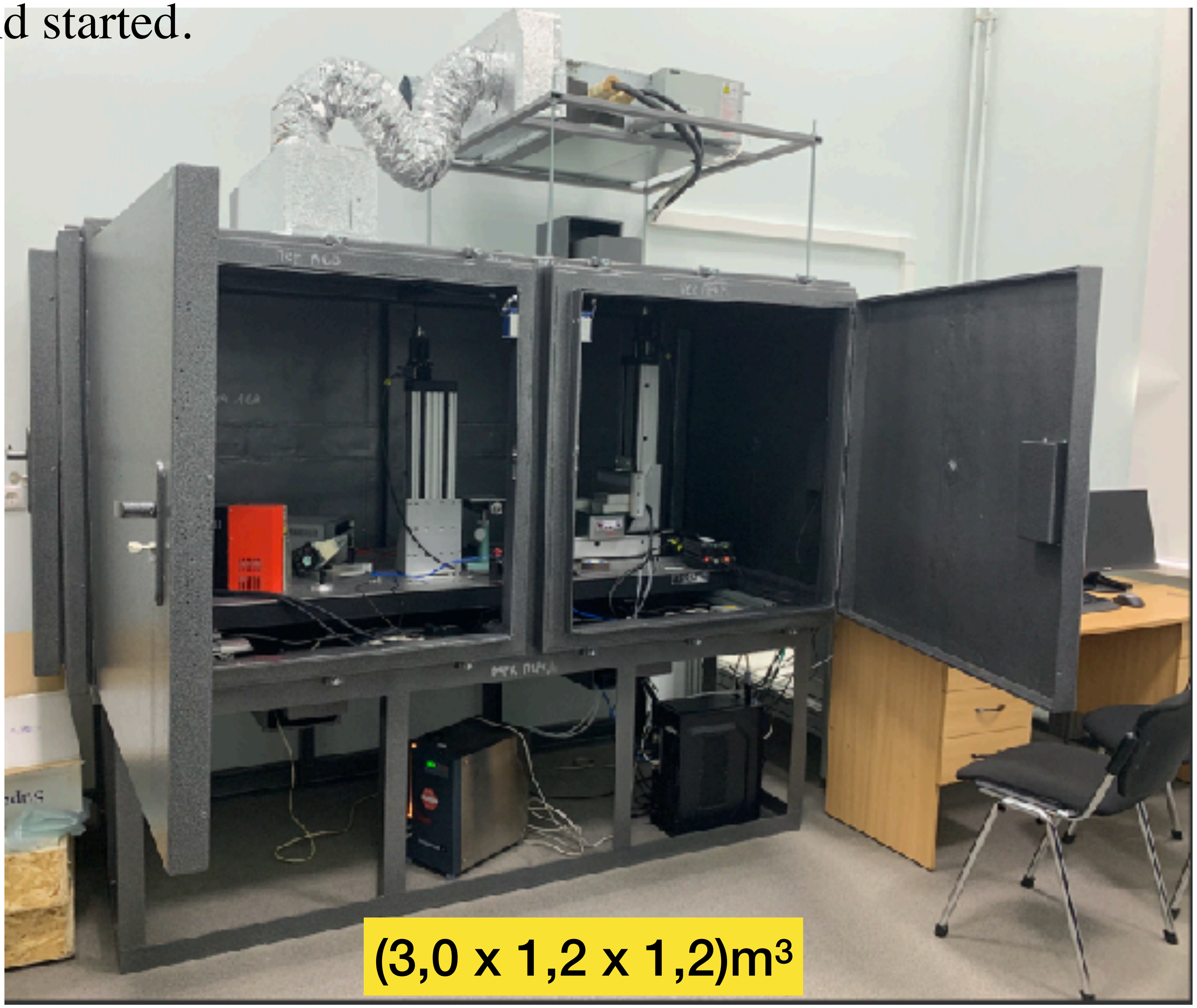
3. The comparison of the responses from detectors with different sensor layer thickness (500µm and 1000 µm) permits estimating the charged and neutral radiation components as 20% and 80%, respectively, of the total radiation level.

4. The detector responses recorded in LHC shutdown periods arise from the decay of four specific isotopes that were activated in the GaAs material by neutrons during periods of beam collisions. The known decay constants and neutron capture cross-sections of these isotopes permit an estimate of the neutron fluence during beam collisions, and by virtue of the different energy dependence of the cross-sections even of the neutron energy spectrum.

A set of all diagnostic tools for doctors about 100 years ago

The main results obtained during the previous stage of the theme

To carry out multi-energy tomographic scanning of various objects with a large geometric magnification, a Kalan-2 microtomograph with a rotating sample was created in NEOVP LAP. It is currently being assembled and started.



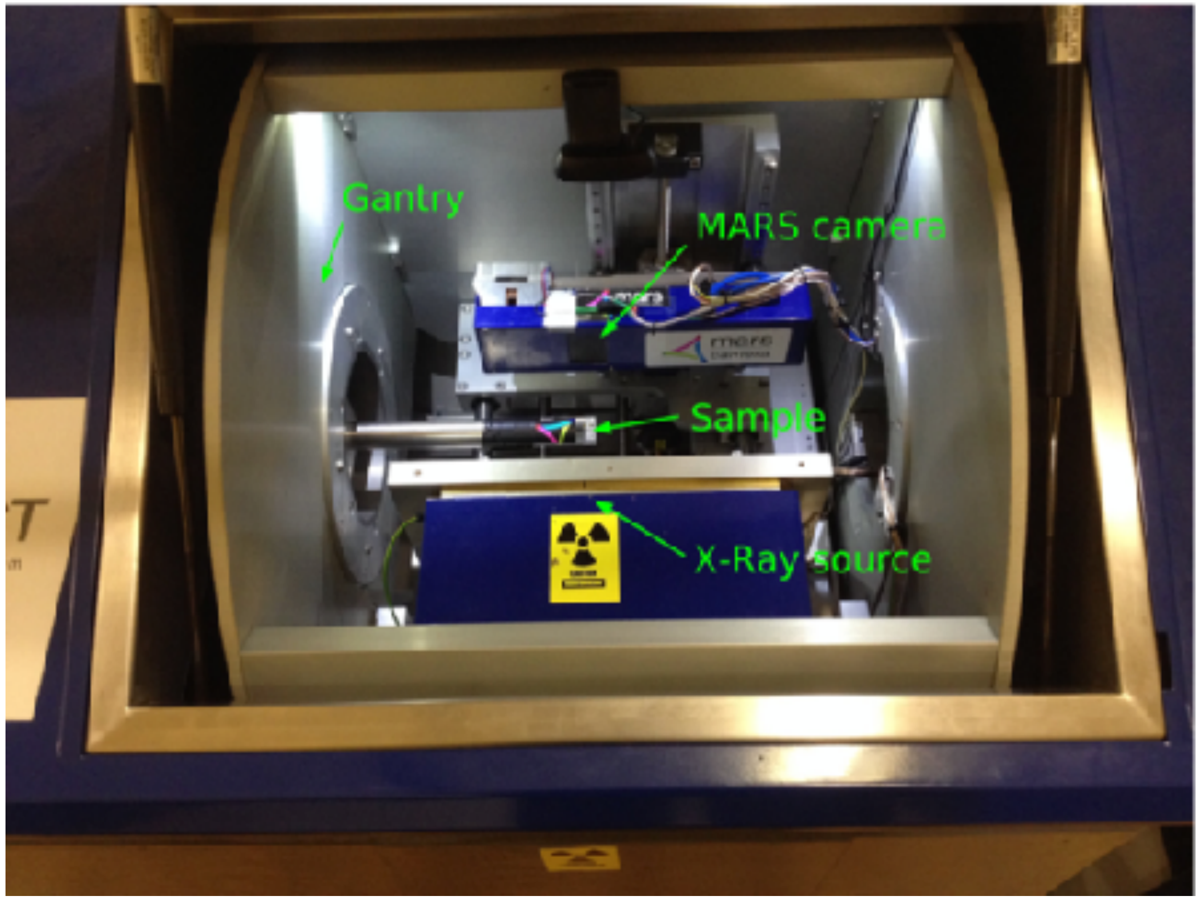
STANDA's motorised stages with controllers were used. The ability to program these devices allows you to configure the different CT scheme for a specific test sample with minimal cost.

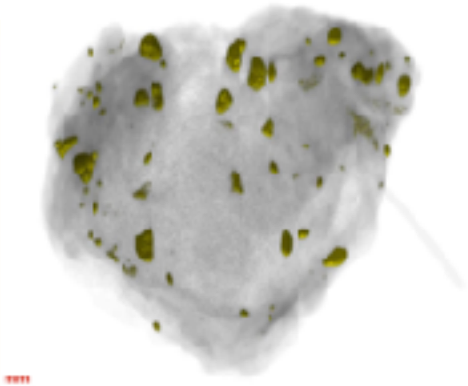
The main results obtained during the previous stage of the theme

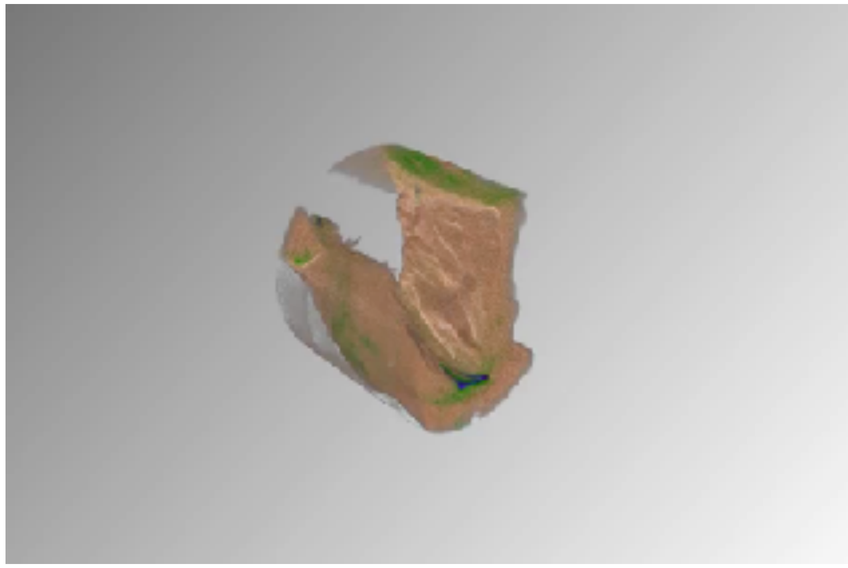
Micro CT MARS

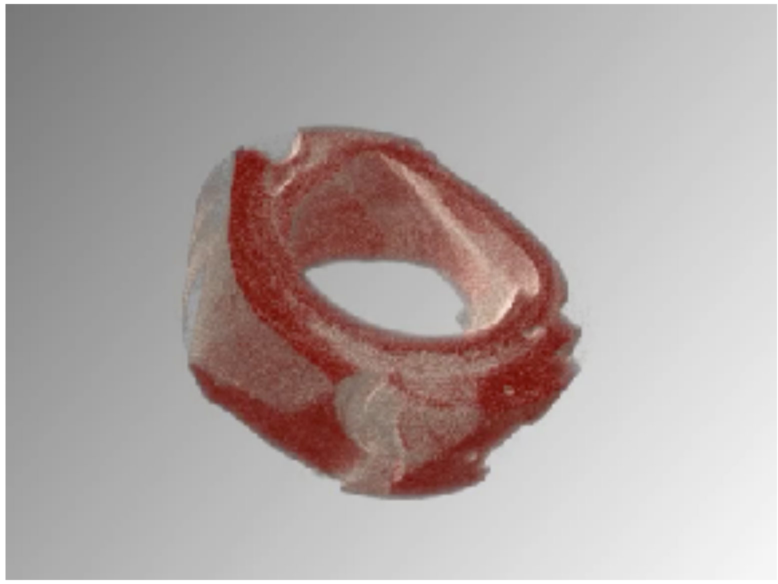
Scanning of biomaterial as part of a joint research program with physicians.

Scanning of ores and minerals as part of a joint research program with geophysicists.









The main results obtained during the previous stage of the theme

Construction of the setup for measurements with electron testbeams at DLNP (Linac-200)

A stable electron beam with an energy of up to 200 MeV was obtained.

List of publications for 2018 - 2020.

1. H. Abramowicz, A. Abusleme, K. Afanaciev, G. Chelkov, et.al. Measurement of shower development and its Molière radius with a four-plane LumiCal test set-up, //Eur. Phys. J. C (2018) 78:135

2. G.Chelkov, B.Bergmann, S.Kotov, P. Smolyanskiy, U.Kruchonak, D.Kozhevnikov, Y.Mora Sierra, I.Stekl, A Zhemchugov. Properties of GaAs:Cr-based Timepix detectors, // Journal of Instrumentation. Vol. 13, no. 02. T02005. (2018)

3. Savelyeva, E. N., Burikova, T. V., Masagutov, R. K., & Kozhevnikov, D. A. Compacting processes and their effect on reservoir properties of the Pashian horizon in Kitayamskoye field (Russian), // Oil Industry Journal, 2018(04), 26-28

4. Kozhevnikov D., Smolyanskiy P. Stack of Timepix-based detectors with Si, GaAs:Cr and CdTe sensors with optimized thickness for spectral CT, // 20th International Workshop on Radiation Imaging Detector, June 24-28, 2018, Sundsvall, Sweden

5. Kozhevnikov D., Smolyanskiy P. Equalization of Medipix family detector energy thresholds using X-ray tube spectrum high energy cut-off, // Journal of Instrumentation. 2019. T. 14. №. 01. C. T01006.

6. F. Dachs,J. Alozy,N. Belyaev,B.L. Bergmann,M. van Beuzekom,T.R.V. Billoud,P. Burian,P. Broulim,M. Campbell,G. Chelkov,M. Cherry,S. Doronin,K. Filippov,P. Fusco,F. Gargano,B. van der Heijden,E.H.M. Heijne,S. Konovalov,X.L. Cudie,F. Loparco et al. Transition radiation measurements with a Si and a GaAs pixel sensor on a Timepix3 chip, // Nuclear Instruments and Methods in Physics Research Section A, Vol. 958. 2019

7. M.Krmar, Y.Teterev, A.Belov, S.Mitrofanov, S.Abou El-Azm, M.Gostkin, V.Kobets, U.Kruchonak, A.Nozdrin, S.Porokhovoy, M.Demichev. Beam energy measurement on LINAC200 accelerator and energy calibration of scintillation detectors by electrons in range from 1 MeV to 25 MeV. Nuclear Instruments and Methods in Physics Research Section A, Vol. 935. 2019

8. Abramowicz, H. et al. FCAL Collaboration Performance and Molière radius measurements using a compact prototype of LumiCal in an electron test beam. Eur. Phys. J. C 79 (2019) 579

9. M.Eseev, P.Horodek, V.Khilinov, A.Kobets, V.Kobets, I.Meshkov, O.Orlov, K.Siemek, A.A.Sidorin, Development of Positron Annihilation Spectroscopy at Joint Institute for Nuclear Research, Acta Physica Polonica A 136 (2019) 315.

Patents

1. Abdelshakur S., Demichev M. A., Zhemchugov A. S., Kozhevnikov D. A., Kotov S. A., Kruchonok V. G., Smolyansky P. I., Shelkov G. A.
SEMICONDUCTOR PIXEL DETECTOR OF CHARGED STRONGLY IONIZING PARTICLES (MULTI-CHARGED IONS),
Patent (RU) 2659717, dated 03.06.2018, JINR.

2. Zhemchugov A.S., Kozhevnikov D.A., Kotov S.A., Kruchonok V.G., Leiva F.A., Smolyansky P.I., Shelkov G.A.
PLANAR SEMICONDUCTOR DETECTOR,
Patent (RU) 2672039, 11/08/2018, JINR.

PhD theses

1. P.I. Smolyansky KFMN (01-04-01) 2018 (leader A.S. Zhemchugov)
"The study of pixel arsenide-gallium detectors based on the Timepix chip"

2. D.A. Kozhevnikov KFMN (01-04-01) 2019 (supervisor G.A.Shelkov)
"Development of the method of multi-energy x-ray tomography using detectors based on microchips of the Medipix family"

Master Degrees

1. E.A. Cherepanova (MIPT) 2019 (head G.A.Shelkov)
"Analysis of the structure of the radiation background in the underground hall of the ATLAS installation based on data from the detectors of the ATLAS-GaAsPix system"

2. V. Andriyashen (MIPT) 2019 (supervisor A.S. Zhemchugov) "Development of a method of multi-energy iterative tomographic reconstruction"

Plan 2021-2023 гг.

FCAL	Creation of a full-scale prototype of the FCAL module; Participation in the development of adequate electronics; Performing beam tests at DESY.
Pixels	**Development of detectors, electronics and software for Timepix4;** Creation of an operating model and software for the “head” CT and; Organisation of collaboration with: - MIPT and MSUmbiophysicists on a MARS μCT;; Development and creation of SPECT / CT system.
Rad. Hardness	Together with Tomsk physicists, the creation of radiation-resistant samples of GaAs sensors; Measurement of the radiation resistance of these samples using neutron and electron beams at JINR;
Linac 200	Commissioning of the linear electron accelerator LINAC-200

Total estimated cost of the theme

№№	Activities	Total cost (kUSD)	Costs per years (kUSD)		
			1st year	2nd year	3rd year
1.	**Internet links**	**10.0**	**3**	**3**	**4**
5.	**Materials**	**180.0**	**80**	**50**	**50**
3.	**Equipment**	**850.0**	**350**	**300**	**200**
4.	**Travel expenses**	**160.0**	**50**	**55**	**55**
	a. Non ruble zone	135.0	45	45	45
	b. Ruble zone	25.0	5	10	10
	Total	**1200.0**	**483**	**408**	**309**